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Designing an Ardunio-microprocessor-and-Labview-based system for monitoring wave spread in the ground caused by constructing activities

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Abstract. There are many activities such as embankment vibratory rollers, piling, blasting tunnel ... causing wave spread in the ground that affect the surrounding buildings. The high ground wave may damage the surrounding buildings and hence may cause confrontations between the local resident community and the project owners. To determine the radius of vibration of each vibrating source that can damage the neighbouring buildings as the basis for planning, choosing construction technology, and designing damping methods to minimize the risk to the surrounding buildings, It is necessary to measure experimental vibration in the field. This paper describes how to install the Ardunio-circuit-based vibration measuring system ~~,~~ by using labview and shows some experimental results of measuring vibration transmitted to the ground caused by constructing activities in Da Nang, Vietnam. The results prove that the measuring system has a considerably low cost and meets the standards and precision according to Vietnamese ISO 7378 and DIN 4054. The software written on Labview platform is connected to the hardware to collect vibration signals from sensors, analyse measurement data, and then make reports on measurement results in table or chart formats to meet the current standard vibration measuring requirements.

1 Overview of the wave propagation in the soil due to construction activities

The principal wave types that transmit vibratory energy away from a source on or near the ground to a distant receiver include Rayleigh (R-) waves; Shear (S-) waves; Compression (P-) waves. Essentially, these three main wave types can be divided into two categories: body waves, which propagate through the body of the soil; and surface waves, which are transmitted along a surface (usually the upper ground surface) [1].

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The three wave types produce radically different patterns of motion in soil and rock particles as they pass. Therefore, structures will be deformed differently by each type of wave.

The P-, S- and R- waves travel at different speeds. The P-wave is the fastest, followed by the S-wave, and then the R-wave. Along the surface of the ground, the P- and S-waves decay more rapidly than the R-wave. Therefore, the R-wave is the most significant disturbance along the surface of the ground. The R-waves account for 67% of the total energy, S- waves 26% and P-waves 7% when the exciting force is applied vertically to the propagation direction [2]. Several empirical equations have been proposed that describe vibration attenuation through soil for specific cases. The scaled distance approach, presented as equation (1), is commonly used for blasting and pile driving operations [3].

$$V=k\left(\frac{R}{\sqrt{W}}\right)^{-n} \tag{1}$$

where: V - PPV at distance R from the source;

W is the energy of source or rated energy of impact hammer;

k and n are parameters found by plotting V versus R on a log-log plot.

Wiss (1981) [4] notes that k and n are unique for each source and soil type combination and this approach cannot be used without detailed site-specific measurements.

Human perception and response to ground vibration varies widely. It depends on individual sensitivity, the frequency, PPV, duration, and on whether or not the event is expected and if so, whether the vibration is expected to cause damage. There are many standards already setting the limits for the vibration which do not affect humans, such as BS 6472-1: 2008 or QCQG 27: 2010 / BTNMT.

Table 1. The maximum value allowed for the vibration acceleration for construction activities (QCQG 27: 2010 / BTNMT) [9].

No.	Area	Time in the day	The level of allowable vibration
1	Special area	6:00 AM –6:00 PM	75 dB
		6:00 PM – 06:00 AM	base level
2	Normal area	06:00 AM – 9:00 PM	75 dB
		9:00 PM – 06:00 AM	base level

Several countries have adopted standards for evaluating the effect of vibration on buildings. A review of international standards identified the following as being the most suitable for providing guidance as to possible building damage from mechanized construction activity:

- ✓ German Standard DIN 4150-3:1999 Structural vibration – part 3: Effects of vibration on structures;
- ✓ British Standard BS 7385-2:1993 Evaluation and measurement for vibration in buildings, part 2. Guide to damage levels from ground-borne vibration;
- ✓ Swiss Standard VSS-SN640-312a:1992 Effects of vibration on construction.

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Table 2. Vibration guidelines from DIN 4150-3:1999 for assessing effects of vibrations on buildings [6]

Type of structure	Vibration thresholds for structural damage, PPV (mm/s)				
	Short term				Long term
	At foundation			Uppermost floor	Uppermost floor
	0 to 10 Hz	10 to 50 Hz	50 to 100 Hz	All frequencies	All frequencies
Commercial/industrial	20	20 to 40	40 to 50	40	10
Residential	5	5 to 15	15 to 20	15	5
Sensitive/historic	3	3 to 8	8 to 10	8	2.5

Note: When a range of velocities is given, the limit increases linearly over the frequency range.

To support measuring and evaluating the spread of wave in the ground caused by constructing activities so that it is possible to minimize the risk to neighboring buildings, this study designed a low-cost Ardunio-circuit-based vibration measuring system as well wrote a software to collect data and analyze vibration measuring figures. The system has been tested and measured for a number of real projects in the recent periods of time.

2 Designing the system for monitoring ground wave propagation

To design a ground wave propagation system due to the construction work required by TCVN 7378[10] and DIN 4150 [6] and low cost, we use the following hardware: Ardunio circuit and geophone sensor. The LabVIEW environment is used to write a software to connect the sensor to Ardunio and computer, collect vibration signals, and analyse the vibration signals measured. The system block diagram is shown in Figure 1.

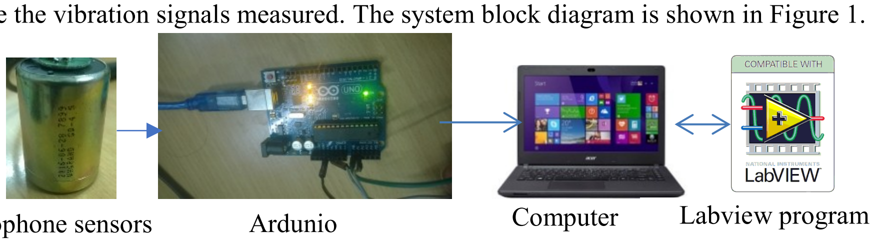

Figure 1. System block diagram for monitoring ground wave propagation

Graphic User Interface of software for collecting and analysing ground vibration signals in figure 2.

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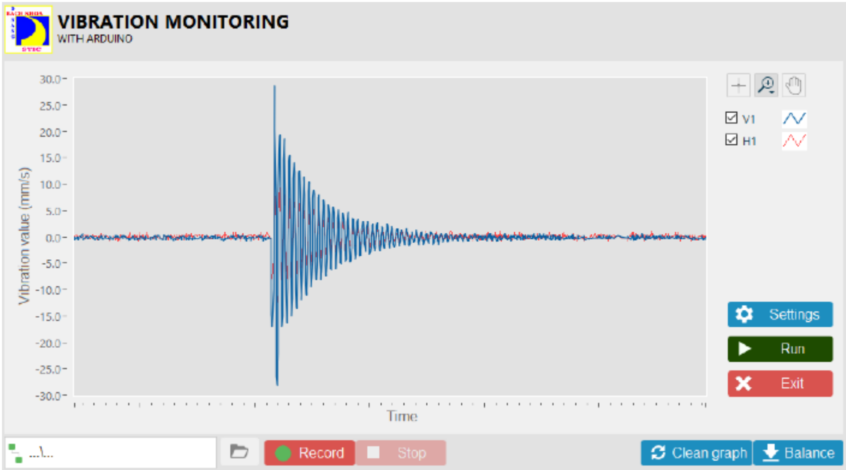

Figure 2. Graphic User Interface of software

Test results of the design system compared with the GPx2 Accelerometer system (USA) on cantilever beam model (Figure 3) show that the free frequency of two systems are similar (10.5 Hz and 11 Hz).

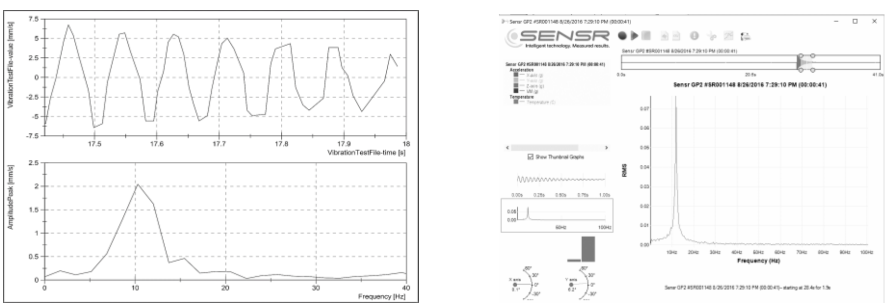

Figure 3. Results of free frequency of cantilever beam model on two systems.

The Arduino circuit cost is about $ 20 compared to other professional dataloggers which cost from $ 500 upwards.

3 Some results of vibration effective radius due to construction activities

Summary results of vibration measurements and determination of the radius affect on the surrounding buildings due to some construction activities in reality are given show in Table 3 [5].

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Table 3. Synthesis of empirical findings vibration measurement projects by the authors of the paper [5]

No	Name of project / regional geological features	Characteristic vibration source	Empirical relationship V (mm/s) and R (m)	Measured vibration frequency (Hz)	Effective Radius R(m) corresponding to Vgh, mm/s	Date of measurement
1	+ Interchange Hue- Da Nang project- phase 1. Pile driven and train + Small sand and clay powder, light grey, humid conditions (depth <= 2m).	1 pile driven machine, Bauer BG25, Fc=235 KN	V= 1000.Fc0.5/ R2.5	6-29	26 (Vgh=4mm/s)	Aug 15, 2014
		Concreting shaft pile	V = 11000/ R2.5		24(Vgh=4mm/s)	
		Pull out steel casing, W=45 kW	V = 20 . W0.2/ R		11(Vgh=4mm/s)	
		Drop steel casing Q=3,5 T, drop height H=1 m	V = 38.(Q.H)0.2/ R		12(Vgh=4mm/s)	
		Train pass	V = 3,5/ R0.25		2(Vgh=4mm/s)	
2	+ Interchange Hue- Da Nang project- phase 1. Road roller + Small sand and clay	1 vibration roller LiuGon CLG614, high centrifugal forces Fc=27T	V = 1800 . Fc0.5 / R2.5	12	29(Vgh=4mm/s)	Sep 25, 2014

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	powder, light grey, humid conditions (depth <= 2m).					
3	+ Ring Road south of Da Nang + Farm land, 1m thick clay; Small-medium grained sand grey white	1 vibration roller C250, Fc=246 kN.	V = 0,5. Fc / R0.9	10-50	30 (Vgh=6mm/s).	July 2, 2014
4	+ Expanding Highway 1A, Km 947-987, Quang Nam province + Sand granules medium grey-white	1 vibration roller Dynapac CA25D, Fc= 160 kN	V = 0,7.Fc0.9 / R	15-21	23 (Vgh=3 mm/s).	June 3, 2014
5	+ Extended Nguyen Tat Thanh Street section from Km 2 + 715.04 to Km 4 + 100, Lien Chieu	1 vibration roller Bomag BW 211D-40, Fc= 236 kN	V = 1,2 * Fc / R1.35	27-35	29 (Vgh=3 mm/s).	Oct 9, 2015
		2 vibration roller BW 211D-40,	V = 1,25 * Fc / R1.25	27-35	39.5 (Vgh=3 mm/s)	

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	District, Danang city. + Granulated sand, white	Fc= 236 kN				
6	+ High Da Nang -Quang Ngai Expressway. Tunnels through the EO mountain (Package 4)	Explosive type P113; weight Ptn=102 kg	V = 4500*Ptn/R2	39-184	391 (Vgh=3 mm/s)	Nov 26, 2015
		Explosive type P113; Explosive weight Ptn=420 kg	V = 4500*Ptn/R2	39-184	794 (Vgh=3 mm/s)	
8	+ Halam Bridge, Da Nang-Quang Ngai Expressway + clay farm land; up ground on the hill.	1 vibration roller Bomag BW 211 D-40; Fc=236 (kN)	V = 0,35 . Fc / R0.9	14-28	33m (Vgh=4 mm/s)	Aug 28, 2014
		1 Vibration hammer Towen 90kW; W is the capacity of vibratory hammers= 90 kW	V = 30 . W0.4 / R	14-28	45m/ vgh=4 mm/s	

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9	Construction of wastewater collection system around the Phan Lang lake and sewers for collection and sewage pumping stations along Nguyen Tat Thanh	1 Vibration hammer PCF-350; W is the capacity of vibratory hammers= 45T.	$V = 6,1 * W^{0.99} / R$	29-39	88m (V_{gh}=3mm/s)	Aug 8, 2016
10	Project against the sand sedimentation in the estuary Phu Loc - Danang city.	01 diggers mounted hammer KOMATSU Type DPD350; Fc =300 KN the vibration force of the hammer	$V = 77*Fc/R^4 +1.1$	13.4-25.2	11 m (V_{gh}=3mm/s)	Jan 26, 2016

Note: V (mm/s) = PPVs (Peak Particle Velocity) of ground; R (m)= adversely affect Radius to neighbouring buildings from the vibration source; Vgh(mm/s) = Vibration velocity limits to protect adjacent buildings.

Table 3 shows the radius of influence due to vibration of various construction equipment; it does not only depend on sources of vibration characteristics but also on regional geology conditions.

4 Conclusions

Measurement systems for ground vibration monitoring activities due to construction based on vibration velocity sensor (geophone) and ardunio circuit connected to specialized software built on the platform language labview meet the system requirements of a vibration measuring equipment such as TCVN 7378 or DIN 4150-3. Precision of designed vibration measurement system is equivalent to the imported vibration measurement system as GPX (SENRS-USA) but the cost is smaller.

The application vibration measurement system designed to application possibilities of the system design are very good. The measured data from actual projects can be used to predict the radius of influence of vibration sources from construction activities on neighbouring buildings.

The system can be extended to a wide variety of other sensors for measuring purposes and health monitoring of different structures.

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